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Securing Unlimited Water Supply in Adelaide over the Next Century

Balancing Desalinated and Murray-Darling Basin Water

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Abstract

This paper assesses the two major water supply options for a growing but relatively dry metropolitan Adelaide – desalination and expanded trading of water from the Murray-Darling Basin (MDB). What we present in this paper is a portfolio approach suggesting a mixed strategy of desalination and water trading to meet growing demand over the hundred year period from 2014. Crucially, the scope for expanding water trading keeps *average* costs down, for as long as the political agreements work and drought does not prevent the use of allocations. However, our modelling shows that in the long run water trade in combination with modular augmentation of desalination capacity can achieve a mix of security and cost that avoids spikes in market prices of MDB allocations during drought. The strategy also avoids the real business and household costs, loss of garden value and inconvenience of water restrictions.

Keywords: water portfolio, water costs, desalination, augmentation costs, entitlement, allocations.

JEL codes:

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The paper is one of a sequence as part of a Deakin University led research project jointly with Griffith University, entitled "*Desalination – the Bigger Picture*", for the National Centre of Excellence in Desalination in Australia, 2012-14.

1. Introduction

This paper examines the future water supply situation in Adelaide, a relatively dry city in South Australia, in the driest populated continent on earth. We analyse a diversified strategy with a new *portfolio mix* of core bulk water:

rainfall-independent desalinated water from the ocean and

rainfall-dependent water from catchments such as the Mount Lofty Ranges (MLR) and water piped from the Murray-Darling Basin (MDB).

Our focus is on the indicative quantity, costs and risks of water supply, and associated augmentation choices and trade-offs, over the next century to 2114.

We model using historically-based projections of drought risks and growth pressures, reflecting a century of rainfall and catchment inflow data based on Bureau of Meteorology and S.A. Water historical data. We thereby avoid the pitfalls of populist commentators on the desalination investments who say, in effect, that the investments were unwise because the drought ended. We also avoid any dependence on scenarios conditional on predicting climate change. What we have is a flexible cost and security balanced model, with expanding modular units of desalination capacity when justified, and with average costs stabilised through trading MDB or river water, except where prevented by drought. While not rejecting scope for including treated wastewater or stormwater when economic or cost-effective, we place modular desalination more firmly in the mix of long-term base load and drought solutions in all cities with volatile rainfall, growing demand and ocean access (see Appendix C).

In papers focusing on South-East Queensland, Sahin, Stewart and Porter (2014) also examined the possibility of introducing drought-related tariffs (DWT) on rain-dependent water. We see such water charges as financing desalination plants within the water supply portfolio in line with resulting demand. Sahin and Stewart (2013) also examined the role of desalination within a mix of demand management strategies, dams and recycled water with respect to long-term planning and the frequency, severity and costs of droughts. In this paper however we leave aside drought-related tariffs, but assume prices of traded river water are positively related to drought conditions, varying between $0.50 and $2.50 per kilolitre.

We also build on papers related to desalination for Melbourne [Porter et al. (2014) and Scarborough *et al.* (2014)] which examine water supply augmentation through comparisons of cost and security of desalination and dams. In those papers it is shown that desalination plants with their minor land footprints relative to catchments for dams, become *relatively* cheap flow sources of new water as population grows. Locations suited to desalination (near oceans and a reasonable distance from populations) are relatively more abundant than secure catchments of the quality around the base load Thomson Dam in Victoria. Dams require huge areas of secure, safe and unspoiled runoff space, with restricted animal access, but such land is increasingly scarce and expensive due to expanding urban populations, agriculture, pollution and industry.[1] Desalination is assumed in those papers, and in this study for Adelaide, to successfully address the shortage of rainfall *flows,* whereas dams add storage for rain that may not fall, or pipelines that may not (be politically allowed to) deliver across water basins.

This paper applies what we label a portfolio approach towards optimal water supply. In particular, we focus on the trading of MDB entitlement "shares" and allocation "flows" in the presence of desalination as what might be labelled a risk-moderating "swing supplier". The portfolio approach requires consideration of both risks and costs of each water supply option. The effect of offering risk-return choices in water supply is that water and water security become like other inputs – scarce but *produced* joint inputs – not political products.

On the risks of water portfolios, a major finding through our simulations is that demand and population factors more than drought or constraints of nature are the real and looming source of long term shortages of supply relative to demand. However, short-term risks differ depending on the composition of the supply portfolio. Expanding dams and pipelines will allow a greater share of MDB water to be accessed, but at increasing drought and political risk. A problem with the MDB as a source, is that water allocations are rainfall dependent, unpriced and deeply political across state boundaries. Releases are positively related to rainfall (i.e. they decline in drought as the originating regions claim first supply), even if catchments may look quite adequate for the Basin. Thus the MDB process is a pro-cyclical and partly political system, unlike independent and thus potentially anti-cyclical and ultimately market based desalination. Over the next 100 years demand may nearly treble, but the water volumes and the battles over sharing MDB water, dams and pipelines may at best remain the same. Thus, it is the gap between demand and supply that, absent desalination plants, will generate *increasing* water supply crises in Adelaide and elsewhere[2].

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[1] For example, the largest desalination plant in Australia, at Wonthaggi (150GL) occupies less than one thousandth of the land for the Thomson Dam in the case of Melbourne, see Scarborough *et al.*(2015)

[2] SA Water purchased about half of water consumed in Adelaide in 2008-09 from the MDB, including 106 GL of temporary water for "critical human needs". Afurther 60 GL was purchased in 2009-10 (see Caica 2010 and

The value of bulk water portfolio diversification into desalination is via reduced extremes of prices and increased security of supply despite drought; ending water restrictions. Economic and environmental risk both fall with a mix of desalination and trading of river water. Yes, there will be costs due to desalinated water thanks to its relative energy intensity. But when the mix of water supply is costed over a century of rainfall cycles, it becomes clear that reliable long-term contracts for water supply will probably be cheaper and more secure with less new dams and more desalination.

Simple short-term unit cost comparisons of bulk water sources also miss the “value” and existential point. For some communities desalination can allow all customers a water guaranty. Water insurance and expansion or development of new communities would otherwise not exist or have unreliable fresh water supply. In portfolio terms it does not make sense just to compare options at a point in time in terms of current unit costs of water per kilolitre. What development hinges on is what can be produced or delivered using *secure* water supply and the resulting income potential, population and the general amenity of life. With sound portfolio management, the value of water contracts and security can be transformative of under-populated areas, and produce output that may justify resulting water costs. After all, the rich countries of the world price water highly, but it is a very low percentage of income earned.

Viewing desalination plants as insurance does raise questions of whether the “premium” is worth it. This paper addresses that question by noting the capacity of desalination in Australian cities to prevent escalation of traded water prices during droughts and reducing the drain on the River Murray and other external sources.

Large-scale desalination options significantly were chosen by five state governments[3] over the two last decades in the context of the Millennium Drought, helped in some cases by modest

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Maywald 2009). Had the drought continued, those levels of imported or traded water would have been both expensive, if available at all.

[3] The Productivity Commission (2010) reports the plants as follows:

State Desalination Plants

	Initial capacity	*Maximum expandable capacity*	*Initial (and expandable) capacity as a percentage of annual consumption in 2009-10*	*Initial investment*	*Completion date*
Units	GL/year	GL/year	%	$m	year
Sydney (Kurnell)	90	180	18 (36)	1 890	2010
Melbourne (Wonthaggi)	150	200	43 (57)	3 500	2012

Commonwealth funding. However, because drought was followed by heavy rains and floods (except in Perth) it was easy for many critics retrospectively to claim desalination plants as unwise investments[4]. But as flagged at the outset, using hindsight in the case of water supply and Australian drought is a bit like viewing everyday insurance policies as wasted unless there is a fire, death, accident or burglary.[5]

In Section 2 we discuss use of the River Murray water in Adelaide and the potential role for desalination. In Section 3, we provide an overview of the model, and key cost and supply scenarios that inform our analysis, before moving on to the key portfolio management simulations and discussion. In Section 4, we conclude with a discussion of the stylised facts and policy implications that arise from desalination options. We also identify areas for future research, and in Appendix B document quantitative assumptions and the systems dynamic framework and associated software.

2. Background: Water Supply in Adelaide

2.1. Sixty Years of Reliance on the River Murray

South-east Queensland (Tugun)	49		25	1 200	2009
Adelaide (Port Stanvac)	100		80	1 830	2012
Perth (Kwinana)	45		18	387	2006
Perth (Binningup)	100		40	1 400	2012
Total	**534**	**674**	**35 (45)**	**10 207**	

[4] As Premier John Brumby stated in an aside at a NCEDA research conference in Melbourne in December 2012, if the drought had continued just a couple more years, and governments had *not* facilitated desalination investment, those governments would in his view have been the subject of ridicule for the resulting economic and social disruptions!

[5] The value added by the insurance industry (estimated at $142.4 billion p.a. between March 2012 and 2013, Australian Bankers Association Insurance, 2013) reflects the annual premiums voluntarily paid for risk alleviation.

The capital city of the “driest state in the driest inhabited continent” on earth,[6] Adelaide has always faced risks of drought and has had an extreme dependence on the River Murray.[7] Debate over rainfall, water supply, dams and suitable areas for farming has been intense[8] and deeply political, The relatively large reserves of water in the MDB and the relatively modest cost of pipelines and transfer dams, eventually made a strong case for a piped connection to the River Murray, as achieved in 1948. The resulting Mannum-Adelaide pipeline, and subsequent Murray Bridge (Onkaparinga) pipeline in 1968 (SA Water 2014) (illustrated in Figure 1), addressed this barrier to development (Connell 2007).[9]

Figure 1: S.A. Murray River Pipelines

The advent of affordable rain-independent desalination further secured water supply, through investment in 2008 in a $1,824 million, State and Commonwealth funded desalination plant at Port Stanvac, capable of meeting up to 50% of Adelaide’s current annual water demand. Pumped supplies from the River Murray have historically met an average 40% of Adelaide’s water supply; increasing to over 90% in dry and low inflow years. Thus despite being a climate-dependent source itself, the River Murray has provided Adelaide not only cheap base load supply in average years, but water security in dry years. This was exemplified in 2006/07 when 91% of Adelaide’s water supply was derived from the River Murray (Government of S.A. 2009, Caica 2010).

[6] See: Government of SA (2014a).
[7] See Hammerton (1987) for a detailed history of water supply and demand in SA.
[8] The great drought of 1865 led Surveyor-General George Goyder to advise the SA Government to discourage farming north of the line, defined by him according to his judgements on rainfall, soils and vegetation. See: Meinig (1962).
[9] What is striking from Figure 1 is of course the proximity of towns to ocean as well as the River Murray.

While Adelaide's current demand of approximately 200 GL/p.a. is only 1% of catchments in the MDB (the peak exceeds 22,000 GL; but in Nov 2014 catchments were at 58% of this peak),[10] the problem is that the MDB, like catchments around Adelaide, is deemed at risk, not least by irrigation farmers along the Murray, who might grow premium crops along the Murray region if they felt secure. Thus, when Adelaide seeks to pipe more from the east at times when drought conditions prevail in both areas, the trading of rainfall dependent water becomes problematic, and desalination opportune.

The shortfall from the Mount Lofty Ranges' reservoirs, and dependence on the River Murray, occurs in part due to low storage capacity.[11] Adelaide has storage capacity currently equivalent to one-year's annual demand (200 GL/p.a.), far less than all Australian mainland capitals (SA Water 2014). The pipelines tap into the vast storage capacity in the east when required, avoiding Adelaide reservoir costs, unlike other mainland capital cities where new and large dams were built over the fifty years prior to the Millennium Drought. Thus, in dry, pre-desalination years, Adelaide increased its demand from the River Murray, while eastern cities were able to draw down reserves.[12]

The sharing of water supply across the MDB has caused a century of debate between New South Wales, Victoria and S.A., notably at election times, as highlighted over the 2012 MDB Plan.13 The Constitution (sec 100) states "The Commonwealth shall not, by any law or regulation of trade or commerce, abridge the right of a State or of the residents therein to the reasonable use of the waters of rivers for conservation or irrigation. What seems clear is that State Governments can decide how to distribute water rights among demand categories within their state.[14] While accounting on average for only 7% of total extractions from the River, SA's use of the Murray can cause disputes with users in New South Wales and Victoria primarily because of SA having limited bargaining power, being at the end of the river system and also having modest (one year) storage capacity. But this changes with desalination.

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[10] For catchment volume see Commonwealth Environmental Water Office (2014, p. 3) or http://www.mdba.gov.au/river-data/water-storage

[11] The storage capacity also implies substantial short-run variability in the needs of the River Murray. For example, while in 2006/07, 91% of Adelaide's water supply was derived from the River Murray, but just one year earlier, 2005/06, only 49% of water supply came from the Murray (Government of SA 2009).

[12] The proportionately greater storage capacity enabled substantial accumulation of water supply in wet years to provide for the dry years (NWC 2011a).

[13] The politics across the MDB is the focus of a book by Connell (2007). Similar themes are discussed in NWC (2011) and MDBA (2014). The history of SA and Adelaide's water supply, of which the MDB has been a key contributor, is discussed in Hammerton (1987).

[14] Needs to trade or at least share water including between states led to formation of the River Murray Commission in 1917 evolving into the MDB Commission (post 1985) and the MDB Authority post the Water Act 2007.

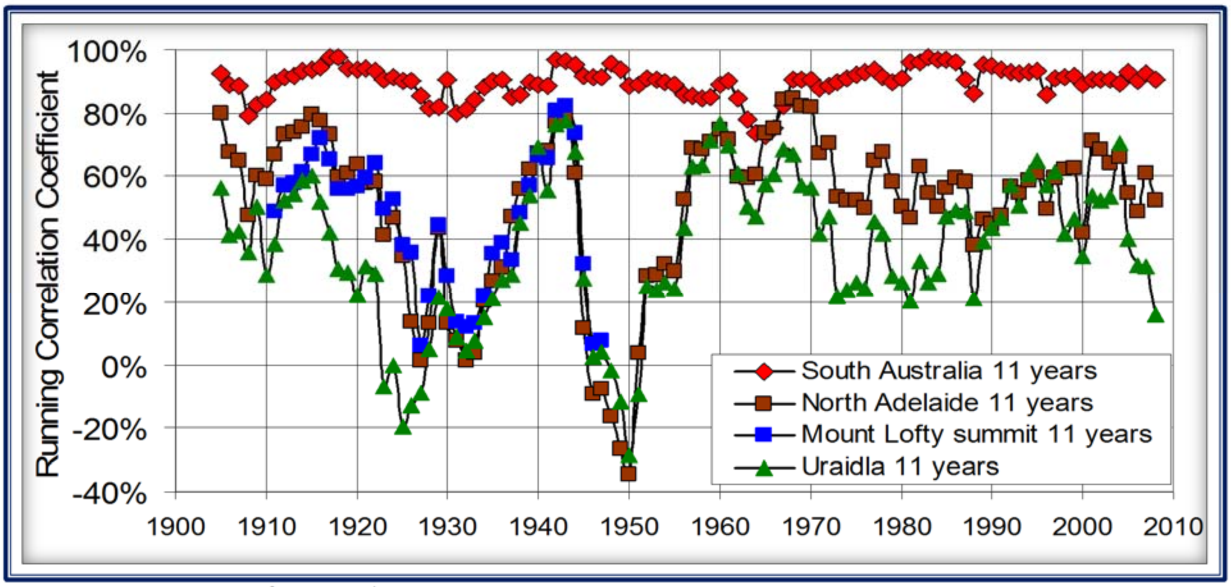
Water rights across the MDB consist of two parts, an ongoing entitlement and a period allocation. There are separate (stock and flow) markets for the trade of these products, thanks to reforms under the National Water Initiative that allowed unbundling of water rights from land and mineral rights (NWC 2013).[15] The entitlement is a capital asset; providing an ongoing right to a defined *share* of water in the Basin now and in the future. As a capital asset, entitlements compete to a degree with investments in desalination and additional dams. An *allocation* in a given period, however is much more a timed “bird in the hand”. It amounts to a binding right to a volumetric *flow* of water supply from an entitlement, and the price may be reflective of rainfall and inflow levels, actual or expected. The trade of an allocation transfers access to a volume of water supply for a defined period of time but does not transfer the ownership of the right to the source. The S.A. Government assigns Adelaide a maximum entitlement of 650 GL over any five-year period, which was sufficient to top-up the Mount Lofty Ranges inflows until the late in the Millennium Drought.[16]

Persistent declines in inflows into the Mount Lofty Ranges and River Murray during the Drought meant that in 2008, for the first time since the construction of the Mannum-Adelaide pipeline, the S.A. Government had to purchase water from the market to meet Adelaide’s demand. Over the drought decade to 2008, the average inflow to the Mount Lofty Ranges and the River Murray fell by 36% and 63%, respectively, well below the historical long-run averages (Government of S.A. 2009; MDB Authority 2010). Consequently, in the years 2006/07 and 2007/08, SA’s water allocations were only 44% and 46% of entitlements (Kaczan et al. 2011, p. 13). While moderate historical correlation of rainfall between the MDB and North Adelaide catchments (Figure 2) provides a case for portfolio diversification via pipeline for Adelaide from the Murray (see Porter et al. 2014), SA’s allocations in the drought years reveal the limits and resulting restrictions due to reliance on this strategy. The agricultural communities along the river, notably irrigation including fruit and vegetable famers, suffer from increasing water insecurity, because of Adelaide’s extreme and growing dependence on the pipelines from the Murray. The desalination plant should increase irrigation security and reduce risk for irrigation farmer, by reducing the probabilities Adelaide rather than farmers will take allocation in times of drought.

[15] The National Water Commission (NWC 2011b) discusses the difference between entitlements and allocations as long and short run products. The NWC identifies the different factors that drive the trade of entitlements and allocations.

[16] Other sources of demand for River Murray entitlements within SA include irrigation, country towns and wetlands (Government of SA 2011).

Figure 2: MDB rainfall correlation (11 year running coefficients) with SA, Adelaide and Adelaide Hills



Data source: Bureau of Meteorology 2013.

In 2008, the S.A. Government purchased an allocation of 30,000 megalitres (ML) at a cost of $14 million (SA Water), an average cost of $467 per ML.[17] By the end of the 2009 financial year, the government had purchased 217,000 ML (NWC 2010), a volume twice the capacity of the newly constructed Port Stanvac desalination plant. However, if the drought had continued across both Adelaide and the MDB, reasonable water consumption levels around 2010 - 2013 would have been unsustainable, absent desalinated water. The NWC (2010) stated that the capacity to purchase additional water supply from the Murray alleviated but did not replace water restrictions. However the case can now be made for the abolition of restrictions thank to desalination.

Adding desalinated water to a portfolio with traded water, allows water planners to scrap controls (falsely dignified as “demand management”) as a response to water shortages. Studies of restrictions summarised in the Goyder Institute for Water Research Report (Marchi, Holger and Dandy 2014) provide estimates that reducing water demands by 10% and 20% costs

[17] The market (usually through web-based trades) determines the price at which (stock) entitlements and particular (flow) allocations can be bought and sold. The National Water Commission’s Reports (see for example NWC 2011b) detail factors that drive market prices of allocations and entitlements.

households $70 and $171 p.a. respectively; cost estimates that are important support for investing in desalination plants.[18]

Avoiding restrictions means sustaining the value of investment in assets such as gardens, parks, nature strips and sportsgrounds, plus expenditure on the general amenity of an attractive "green" city. This also means cost estimates of restrictions are understated by restricting valuations to households. Removing restrictions and securing supplies may also reduce fears of metropolitan areas draining water allocations from irrigated farms and businesses, often with premium water-intensive outputs. While we refrain from hazardous estimates of these total benefits, we do know that if a vast dry Australian continent can tap the oceans around our almost 36,000 km of coastline, then development and settlement possibilities could be vast.

2.2. Looking Forward: Desalination and Water Markets

As evidenced through Adelaide in the last decade, trade in water from the MDB held the largest potential benefit because of sheer volumes and existing infrastructure. For this reason the development of a water market in which ongoing (share) entitlements and timed volumetric (flow) allocations can be bought and sold has become highly valued.[19] The argument for strengthening the existence of the market was enhanced through the declaration of sustainable limits to river extraction (NWC 2011b). A cap on extractions, first introduced in 1995 and renegotiated in the MDB Plan (2012), encourages trade, since demand beyond those caps must be met from the market (NWC 2011b). Within a well-functioning market, trade and explicit pricing should in turn encourage transfer of river water to its highest value user.

However, to use the words 'water market' is potentially misleading. Fears of drought and scarcity have caused political resistance to the notion that water should travel to where it is most highly valued, in particular where the trade is from rural-to-metropolitan regions. A prominent example of this is the political refusal to date to use pipelines for water transfer across basins in Victoria, despite 'sunk' infrastructure costs making it way cheaper. Despite the politics, as is evidenced with Adelaide, substantial trading of official entitlements and

[18] If, for example, a million families value water security and an absence of restrictions at $50 per annum, that services that capital costs of a desalination investment of $1 billion.

[19] In 2004, COAG identified the importance of this goal. The goals of COAG led to the National Water Initiative that established the National Water Commission. This subsequently led to the Water for the Future Program of which the MDB Plan was a feature (see: NWC 2014).

allocations is increasingly occurring and evidently beneficial to both buyers and sellers, as with all free trade. Some farmers in particular face a profitable, if not traditional, new line of income.

3. Modelling

3.1. Systems Dynamic Model

To analyse the key issues of adding desalination plant to a water grid we extend a System Dynamic Model (SDM) to an expandable and modular Adelaide water portfolio over the next 100 years. The model is a representation of the volumes, sources, costs and interconnections of bulk supply and demand, enabling studies of means for achieving future water security and comparing alternative costs. We include internal feedback loops of the entire system including determinants of supply and demand, capacity augmentation decisions – dams and desalination, MDB allocations, market purchases and pricing policies, including those responding to drought. The structure is a hybrid, with central regulation and market dimensions.

The model (see parts of the illustrative schema of the sub-models in Appendix A) allows a comprehensive analysis of the time-dependent water supply and demand linkages, and shows the sensitivities of results to changes in key parameters such as rainfall levels, drought frequency and duration, pricing, availability of desalination and other bulk supply and allocations by authorities. The sensitivity measures can include, in differing runs, the discounted infrastructure costs, supply levels in catchments, future supply augmentation costs and changes in the water market supply given growth in population, consumption habits and thus demand over time. The modelling captures interdependencies between population growth, demand, and supply from MLR catchments, aquifers and particularly MDB allocations from SA.

3.2. Simulations of Mount Lofty Ranges Inflows, Government-Assigned Allocations and Demand Growth

We simulate inflows from the Mount Lofty Ranges and government-assigned allocations over the 100 years from 2014 based on rainfall data for North Adelaide from 1900 (Bureau of Meteorology 2013) and recent data on actual River Murray extractions (1984-2013) provided by S.A. Water. We do not pretend to forecast a century ahead; rather we apply the rainfall patterns and droughts of the past century to probable populations and rainfall variability of the future, to indicate the mix and cost alternatives of varying outcomes given demand growth and supply assumptions.

To derive these simulations we first generate random data on future rainfall levels using the historical data, making some adjustments for our drought scenarios. We then estimate the relationship between inflows to the Mount Lofty Ranges and rainfall levels.[20] The estimated coefficients are used to simulate future inflows from MLR and to estimate future water allocations from the River Murray against entitlements.[21]

3.3. Drought Scenarios, Water Supply and Demand

In the model, a shortfall in water supply, and an associated need to purchase allocations in the market, is defined to occur when the sum of ground water, water supply from the Mount Lofty Ranges and Adelaide's government assigned allocation from the River Murray is insufficient to meet projected demand. When such a shortfall occurred in 2008, with no desalination plant on line, the S.A. government purchased additional water supply in the MDB market. In what follows we assess the volumes and costs of a mix of desalination and the flows from the market topping-up those water supply shortfalls, enabling a comparison with a pre-desalination situation.

The suggestion in the extrapolations in Figure 3 is that either (i) S.A. would build a second desalination plant around year 33 followed by a third in year 60; or there would be (ii) greatly expanded use of MDB water trading, possibly requiring duplication or expansion of pipelines from the Murray to Adelaide dams. Existing catchment and MDB allocations including the current desalination plant will need augmentation through purchases or extra desalination capacity.

The desalination response scenario (Figure 4) sees Adelaide capacity growing to three 100 GL/pa desalination plants (including the current Port Stanvac plant) in the context of very little water trading (the diminished red areas in Figure 4 relative to a single desalination plant in

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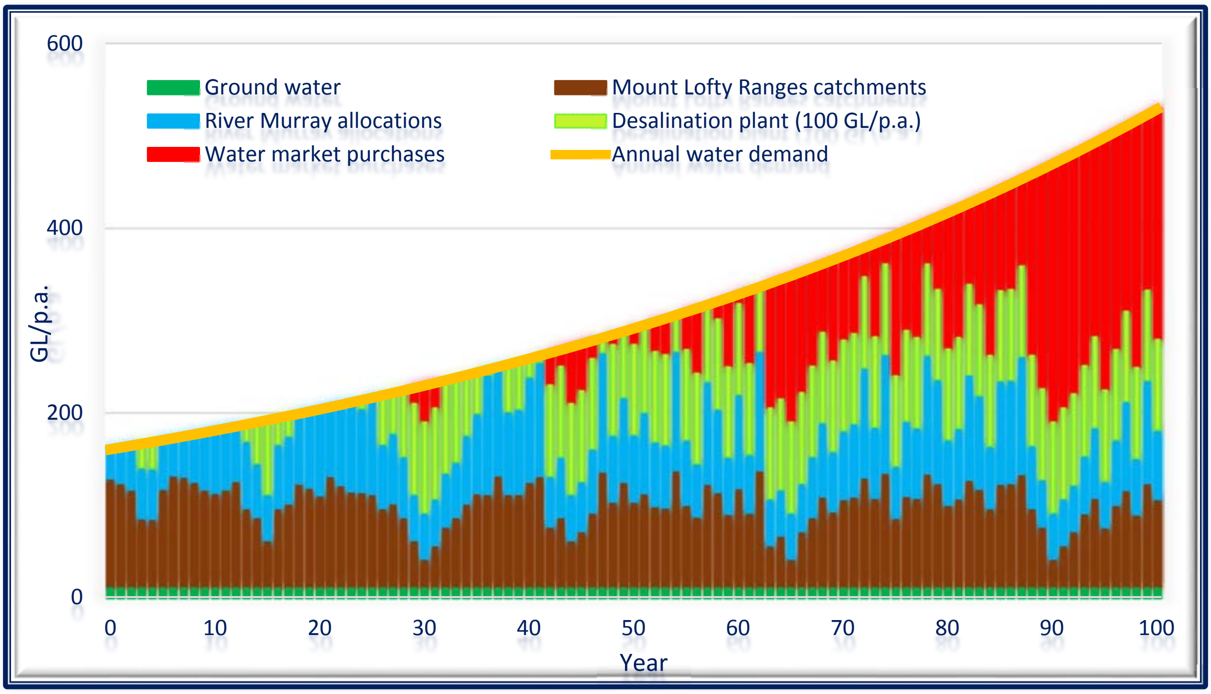
[21] As we identified from Figure 3, Adelaide's allocations originating in the MDB are positively correlated with rainfall in the MDB; meaning probable *reduced* allocations from the entitlements at times water is actually *short* in Adelaide. We therefore create a loop in which variations in allocations and Adelaide's (and the correlated MDB's) rainfall are positively linked. The historical maximum rainfall level of 800 ML/year is linked to the 100% allocation (130 GL/year), the minimum rainfall level of 290 ML/year is linked to the minimum allocation of 40 GL/year, and so forth between these two values. We then run our simulations.

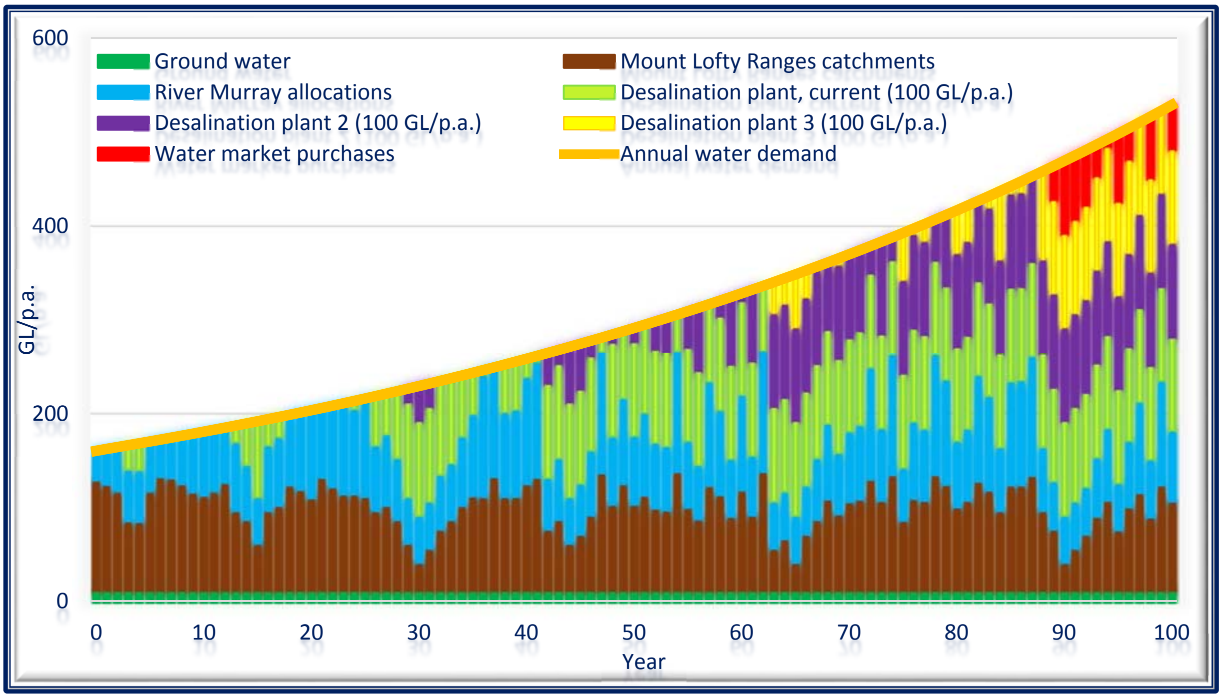
Figure 3).[22] This new situation could be caused by S.A. Government decisions or the eastern states insisting S.A. be less reliant on the MDB (costed below).

Figure 3: Supply and Demand, 2014 – 2114 with five mild droughts and no new investments



[22] If demanded, water augmentation decisions can be made for modules of 50 GL/pa or 100 GL/pa based on efficiency analysis.

Figure 4: Five Mild Droughts, 3 Desalination Plants, Entitlement 650 GL over five years.



3.4. Cost Assumptions

While existing dams and catchments will continue to cover base load demand, as the century progresses, volumes demanded just on a population basis necessitate more traded or desalinated alternatives. The graphs reflect the fact that average unit cost of reverse osmosis desalination has fallen almost 90% over the last two decades, to figures such as $1.30/kL estimated currently for Adelaide. While that figure exceeds combined treatment, pumping and trading costs on average from the Mount Lofty Ranges reservoirs and the Murray-Darling Basin ($0.24-$0.44),[23] it has the advantage of independence from rainfall, unlike surface water.

Trading prices during (including shorter term water storage costs) have varied over the last decade between $0.50 (normal) to $2.50/kL (drought) based on rainfall level, the higher figures being double desalination costs. Our estimates suggest desalination looks certain to be a key part of base load supply by the middle and later parts of the 21st century, and a key part of periods of supply in earlier drought/high excess demand scenarios. The prices of purchased river water will most likely be far higher in future droughts than we have assumed; i.e. we have been conservative in pricing the alternative to expanding desalination. We will show how,

[23] The cost of desalinated water in our models is $1.0/kL + $30 million per 100 GL/p.a. desalination plant capacity.

nevertheless, the major value in desalination investment comes from dampening swings in costs and removing restrictions in response to the almost doubling of total demand, as reflected in Figure 5.

Our earlier Figures 3 and 4 assessed the quantity of water needed to meet demand from a portfolio mix of rainfall independent and dependent water supplies over next century; this section illustrates both quantity scenarios in terms of our estimated costs (i.e. volume multiplied by unit cost per kL).

Figures 5 and 6, plot the costs of a supply mix to meet growth in demand over the century, given Australian Bureau of Statistics population forecasts[24]. Figures show that variation and level of costs with additional desalination plants is significantly less than when dependent on trading from the MDB, making desalination a more secure and cost effective future choice of water supply. An important point is that the contracts secured by desalination will be more valued than those dependent on negotiated but ultimately political allocations. The desalination plant serves as insurance preventing escalation of traded water prices during droughts and avoiding restriction policies. Perhaps more important than insuring the avoidance of price increase and restrictions, use of desalination tells the Murray irrigation farmers that Adelaide is reducing its dependence on the river, and enhancing irrigation farm security.

[24] The sources covered are ground water (barely visible in the graph), Mount Lofty Ranges, allocations from the MDB, desalinated water and water market purchases.

Figure 5: Simulated Total Operating Costs by Source (No New Desalination Plants), Adelaide, 2014-20114

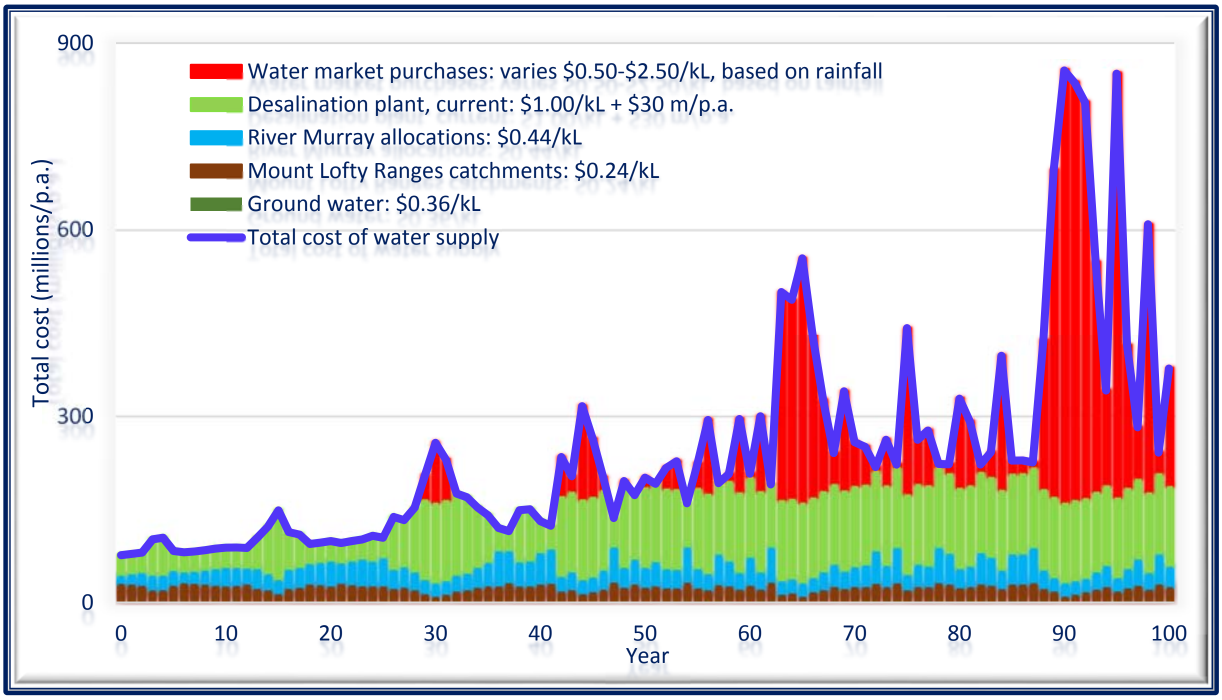
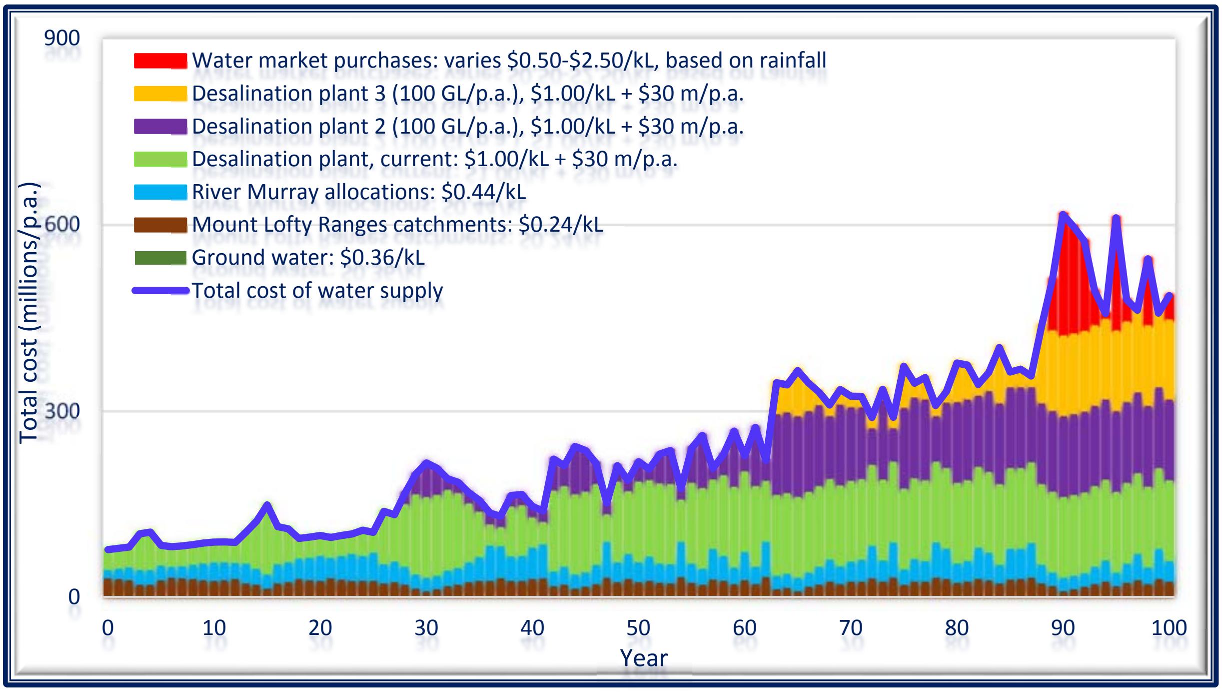


Figure 6: Simulated Total Operating Costs by Source (Two New Desalination Plants), Adelaide, 2014-2114.



3.5. The Cost-Risk Trade-Off: Desalination versus Water Trade

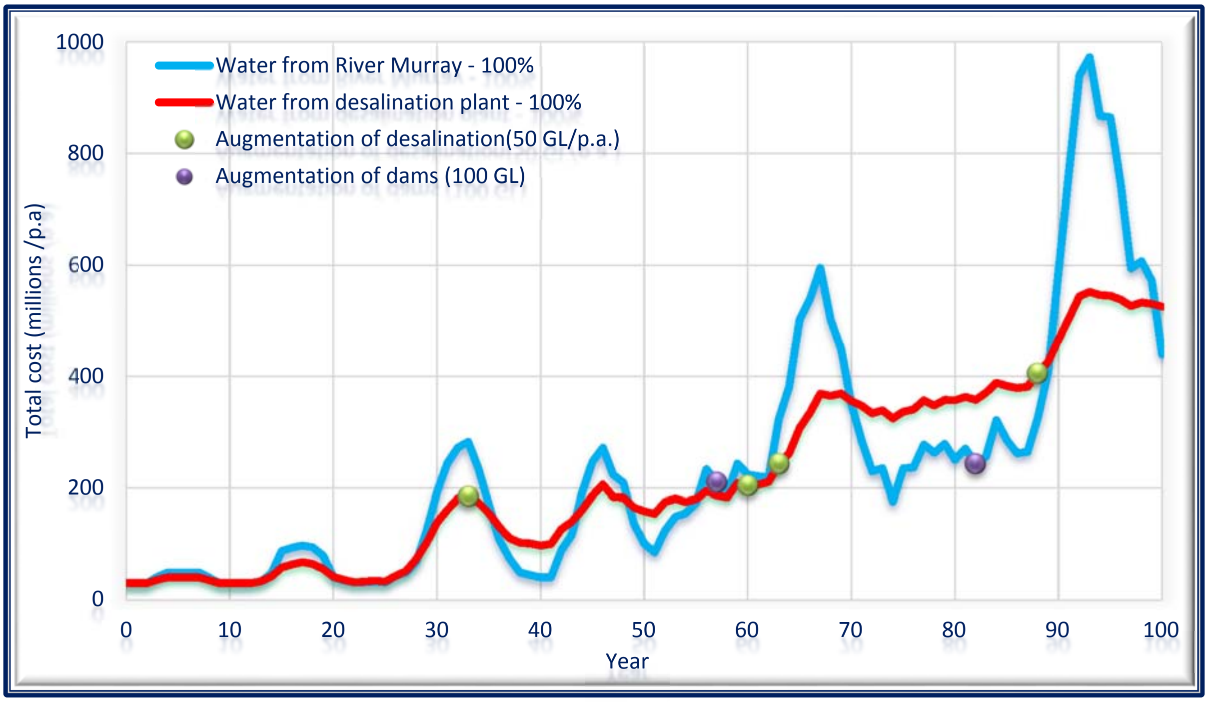
Figure 7 plots estimates of the operating costs of an *either-or* supply scenario in relation to desalination and water trading. The blue line plots the five-year rolling average operating costs for Security Level 1 (ratio of capacity to annual demand) when Adelaide meets demand through purchased allocations from the MDB, with desalination on standby. The purple dots show timing of dam and pipeline expansion costs. The red line projects costs when extra water is sourced solely from desalination, a line that rises as the second, third and fourth 50 GL/p.a. desalination plants come on line (as indicated by the green dots).

While desalination operating costs per kilolitre (kL) are higher on average than pumped and treated river water, this is not true when drought hits, and purchasing water costs far more per kL. (We estimated linear statistical relationships between rainfall levels in the MDB (and MLR) and water trading price average to estimate costs from purchasing water).[25] We should note that Figure 7 almost certainly understates the real costs on the trading or "blue" line, as river water will become increasingly scarce and pricier than indicated by past relationships, due to population and economic growth.

Figure 7 also highlights that for Adelaide, the modelled operating cost of desalinated water is generally higher than from purchasing via the MDB - i.e. from greater allocation trading. What the availability of desalinated water does is avoid peak costs during drought, making average water portfolio costs more stable and predictable. In addition, in the absence of desalination, the spikes in costs during drought, and the drought itself would almost certainly flag a return to costly and inconvenient water restrictions.

[25] The total cost of the blue line includes market purchase price variations from $0.50/kL to $2.50/kL based on rainfall level and annual maintenance cost of new dams at 3.5% of $1.7 billion capital costs for 100 GL capacity. The second new dam comes with the additional cost of a new pipeline, assumed to be $2 billion. The total cost of the red line includes operating cost of desalination at $1.0/kL + $15 million for 50 GL/p.a. capacity, reaching $1.0/kL + $30 million for 100 GL/p.a. capacity, and maintenance cost of 3.5% of $1.2 billion capital investment.

Figure 7: Total Operating Costs, Desalination <u>or</u> Market Trade, 2014 - 2114 (5-year moving average, constant 2014 prices).



The previous section illustrates the extremes of estimated direct cost of top-up supply from desalination <u>or</u> MDB water trading. Any realistic situation will be a mix of desalinated and traded supply, and the total operating cost line would be between the red and blue lines. Figure 7 illustrates the key point. What extra desalination delivers is less water risk, or better water supply insurance, and more secure water contracts; at a smoothed price – as evident in the graphs. While the sum of operating and capital costs over 100 years is similar, with the blue cost line being below the desalination line for substantial periods, the wild up-swings in droughts are avoided with desalination options. This is reflected in the smoothest of the curves being the red (pure) expanded desalination strategy line.

While the increasingly severe swings in the costs of droughts and their long term escalations are evidently avoided by expanding desalination, we note again that we are omitting many of the indirect costs to farmers, for example. Many farmers will walk off their farms or orchards in face of drought, and many water intensive businesses may close. Gardens will die, and parks and housing amenity will "brown" with sustained restrictions, at costs estimated at over $100 per household per year – enough to service the debt on desalination investment, as noted above.

In summary, the availability of an abundance of desalinated water – expensive in normal rainfall (desalination mothball) times – averts disaster for many in drought or rainfall dependent circumstances. Desalination also takes Adelaide pressure off the MDB. This point has recently been made in the media where *The Australian* reports fears of the Murray mouth closing unless allocations to the river are increased. [26]

3.6. Funding the Water Supply Mix: A Comparison of Augmentation Investments

In the previous section, we noted that water supply augmentation would be required over the century whether through purchasing water traded from the MDB, requiring expanded dams and pipelines or through desalination strategies, or as we suggest, a mix of the two. This need for new supplies is because of growing demand relative to supply from local catchments. Our simulations demonstrate that an *extra* water supply "flow" demand of around 230 GL (on top of the current storage capacity in the MLR of approximately 200 GL and the Adelaide desalination plant of 100 GL/pa) will be required to meet growing water demand in Adelaide by the end of the century.

Expanding supply solely through market purchasing of MDB entitlements and allocations to meet additional demand also requires augmentation of Adelaide's modest 200GL storage capacity; i.e. new dam and pipeline capacity to store and pump water from other catchments, principally via the River Murray. Alternatively, a pure desalination strategy requires further desalination plants. The previous section compared the operating costs of these pure strategies; this section compares the full augmentation costs (capital and operating) of the additional dams/pipelines or desalination plants to provide an additional 230 GL capacity or flow, discounted up to the year in question.

Desalination and allocations are both *flow* sources of water supply, with the latter in the case of the MDB having greater cost and volume uncertainty, while also eventually requiring expanded dams/pipeline expansion to increase storage capacity. While investment in desalination flow capacity does not expand storage capacity, it can optimise existing capacity and provide unconditional water flow independent of rainfall. Both drought in the MLR

[26] See: Martin (2014).

catchment areas and reduced flow supply from MDB allocations through the pipelines can be responded to by desalination plants, but not necessarily by drawing on dams, if drought is sustained.

Another way of stating the difference is*: Desalination is very much about reducing flow supply risk. Dams are really about storage – and don't reduce long term water supply risk* - which is the looming question for Adelaide. Both rainfall risks and political risks (from MDB and the eastern states) make desalination the low risk expansion model, and we argue, depending on dam costs and traded water prices, probably the cost minimisation model as the century unfolds. When we add capital and operating costs of restoring water security in Adelaide through expanded dams and desalination, and allow for timing and modularity factors, it turns out desalination will have lower discounted costs – estimated at $4.6 billion at a real discount rate of 1.5% in contrast to $4.9 billion for expanding use of river water at a security level of 1.00. This figure rises to $7.2 billion should dam and pipeline capacity be expanded so Adelaide has a more acceptable (but still the lowest) storage/demand security ratio of 1.25.

*Water costs as a percentage of gross state product *(GSP)*

What is interesting given fears of rising water costs, is that costs of total water supply in Adelaide to the metropolitan areas including desalination are projected to remain at less than 0.2 % of Adelaide's share of Gross State Product[27], indicating water costs are no fundamental barrier to the long term development of Adelaide and the growth areas of South Australia. While individual water accounts may reflect other charges and be in the range of 1%-3% of incomes, the point is that the advent of desalination is more likely over the century to lower costs and raise economic and water security relative to expanding dams and pipelines.

Figure 8 below presents the comparison of required augmentation costs using a 1.5% real discount rate. The augmentation cost of dams include investment, operating, maintenance and other capital costs of a new pipeline.[28] Additionally, in Adelaide's case, if water in excess of current "free" entitlements of 650 GL over 5 years is sourced from water trading, the ***total cost*** of water provided through dams then increases by the additional cost of MDB market purchases.[29]

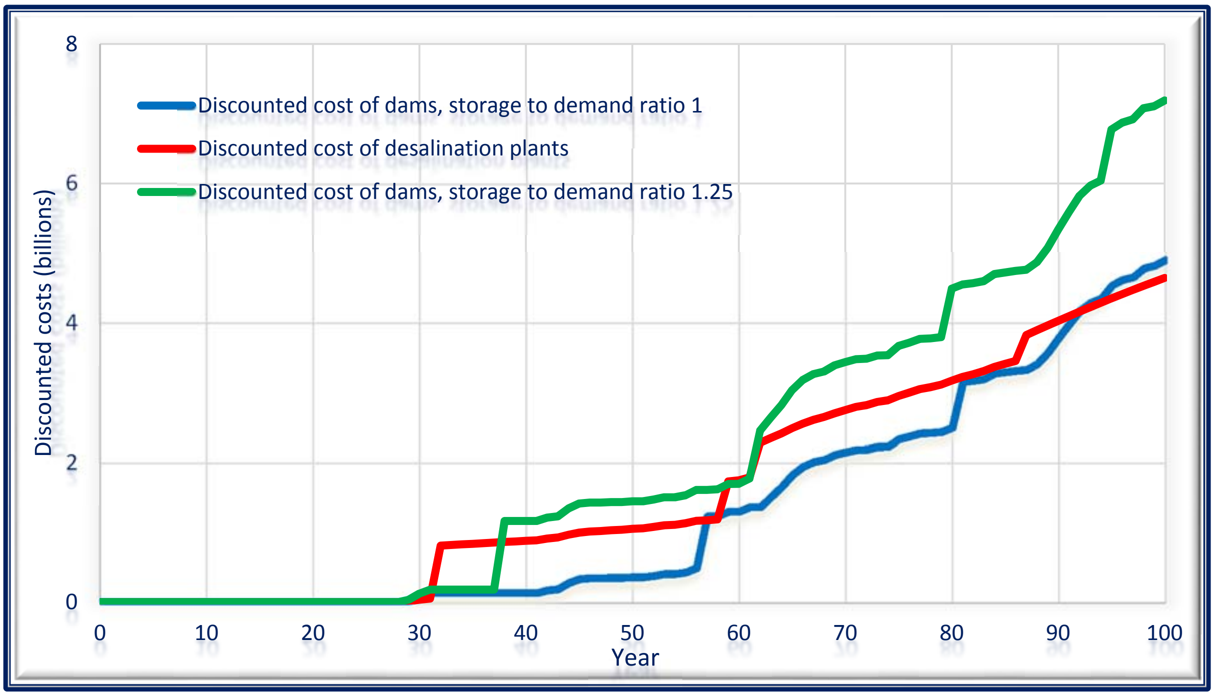
[27] Based on 2013 ABS data for Gross State Product, apportioned to metropolitan Adelaide by population, the ratio of total operating costs including desalination is 0.1? % for 2013 data.
[28] In addition to pumping and treatment costs the operating cost of both dams and desalination plants include maintenance costs of capital investments.
[29] All cost assumptions are listed in Table B1, Appendix B.

Dam and Pipeline Costs in Comparison with Desalination Investment Costs

- Figure 8 illustrates the estimated discounted total costs of expanded water supply, being either the blue line for 100% river water, where the water purchase or market trading strategy includes new dams, new pipeline and market purchases – with a security level (capacity/demand) of only 1.00: *or* the red line using expanding modules of desalination plants
- The green line indicates the sharply higher capital and operating costs of raising security (storage to annual demand ratio) to 1.25, causing an estimated $2.6 billion higher discounted cost relative to desalination and about a $2.3 billion margin relative to the lower current security level (1.00). (Note that the green line representing extra security investment in dams is not plotted in Figure 7 as the costs as indicated from Figure 8 suggest it prohibitive relative to desalination.)

The above costs indicate that at a security level (capacity/demand ratio) of 1.00 Adelaide needs an extra 230 GL of dam storage plus associated pipelines. The dam investments are assumed to be needed around years 57 and 82 from 2014, depending on population and demand growth, at a total capital cost around $3.4 billion in 2014 prices. The first thirty years from 2014 are found to be adequately served by existing storage, desalination (Port Stanvac) and purchase arrangements; requiring no augmentation. Should Adelaide choose the higher security level of 1.25 this extra 360 GL of dam storage and pipeline investments kicks off in the fourth decade in this model. The total costs of sourcing water from rain dependent sources at both security levels are estimated to be *higher* than the total cost of desalination.

Figure 8: Discounted Capital and Operating Cost of Supply Augmentation, Desalination or Dams, at differing security levels **(Social discount rate of 1.5 %)**



We note that at a security level of 1.00 there are twenty four years between the assumed earlier desalination investments and the *alternative* later dam and pipeline investments. This is because the suggested size of efficient new dams is suggested to be 100 GL capacity, with modular desalination plants at 50 GL.[30] A reason for one initial cost disadvantage to desalination is that projected demand and supply conditions are such that the capital cost of the smaller units of capital expenditure on 50 GL plants costs are higher when discounted relative to the later, larger and lumpier capital costs of dams. Equally important, the purchase price of water from the MDB, absent drought, is generally cheaper than desalination costs.

The desalination investment model has the distinct water security advantage over the dams because of the 200 GL of new annual water flow capacity from rainfall-independent desalination plants – the equivalent of more than doubling rainfall-sourced water in Adelaide. Dams enable expanded retention only when the rain comes or river allocations can be obtained. Additionally, desalinated water need not have uncertain costs given long term energy contracts, but as reflected in Figure 7, water purchase prices from the MDB can rise a few hundred per

[30] Dams are measured at this capacity due to data availability on total capital cost of 100 GL.

cent in dry times. While the costs of desalination have an uncertain dimension in energy costs, there are many suggestions of likely cost-reducing membrane and nano technology and energy capture.[31]

Our cost assumptions are set out in Table B1, Appendix B. Given the 100 year simulation period we derive the discounted alternative costs using a modest real social discount rate of 1.5% frequently applied to intergenerational infrastructure investment.

What Figure 8 reveals, is that in the absence of new desalination capacity, growth in Adelaide requires both new dams and expanded pipelines. When we factor in these capital costs, desalination will have discounted costs (capital and operating) that are similar but security levels that are dissimilar – since desalination modules are far more secure and expandable.

The other major result summarised in Figure 8 is that once a 1.0 security level (one year's supply) is seen as unworkable in S.A. as in the eastern states, new investment in dams and pipelines achieving at 1.25 would still leave Adelaide with the lowest water security ratio in Australian capitals. What is notable from this analysis however is the costs of dams to achieve a 1.25 security level significantly *exceeds* the costs of augmentation via desalination through four new 50 GL plants over the century. This in fact is estimated to bring a discounted cost saving $2.6 billion at a 1.5% real rate of discount. And to repeat, this assumes no rapid escalation of real water entitlements/allocation costs as the century progresses and as MDB water is in increasingly in demand. This means the estimated $2.6 billion estimated savings relative to dams may be very conservative.

4. Conclusion: Drought, Desalination and Water Trading

Subsequent rains in Adelaide and the Murray-Darling Basin have meant that with hindsight, Adelaide could have done without the Port Stanvac desalination plant for a decade or more. However desalination is about water supply insurance, and a continuing drought was something no mainland government was willing to ignore. Desalination plants were built as the result of

[31] The cost of reverse osmosis desalination has been decreasing significantly due to technology improvement through optimized processing and higher efficiency energy recovery devices such as pressure retard reverse osmosis (PRO). There are also indications of nano and other energy and membrane-saving technologies in development.

the Millennium Drought in all mainland States and supported in varying ways by the Commonwealth, most generously for Adelaide.

This paper has reviewed the role of desalination in metropolitan Adelaide bulk water portfolios in the next 100 years, in the context of the last 113 years of rainfall data, desalination, dams and pipeline costs. Our simulations show that in the absence of new desalination capacity by the middle of the century, Adelaide will face uncertain but escalating costs of importing water, probable long term water restrictions and threatened water-intensive gardens, sports fields, parks and industries. This is all due to a combination of likely growth in population and the economy in and around Adelaide plus ongoing rainfall patterns. Absent new desalination capacity, Adelaide water supply will increasingly require augmentation through external river purchases about double their current level – assuming a willingness to sell allocations or entitlements from the MDB.

Our simulations also suggest that absent desalination expansion, the need will be for dramatically increasing imports of Murray-Darling Basin water, growing to 200GL by 2114, and at increasingly expensive and uncertain prices. The farming communities will be stressed. There will be political issues interstate regarding water transfers to SA, despite agreements, and increasing water restrictions. The simulated alternative is a sequence of four demand-driven 50 GL units, generating total of 300 GL of desalination capacity over the hundred year period. More likely than *the "either/or" strategy for MDB pumped or desalinated water, is an expanded mix of traded water from the MDB and a sequence of desalination plants with predictable costs*. Such a mixed strategy will moderate periodic spikes in MDB water purchase prices, and reduce the need for, or enable abolition of water restrictions.

Total costs of water supply in Adelaide including desalination to the metropolitan areas are projected to remain at less than 0.2 % of Adelaide's share of Gross State Product. While individual water accounts may reflect other charges and be in the range of 1%-3% of incomes, the point is that the advent of *desalination is more likely over the century to lower costs and raise security relative to expanding dams and pipelines.*

Our story is about more than desalination and trade securing water for the most valued uses. We also argue that removal of water restrictions has a (shadow) value commensurate with or probably larger than the funding costs of desalination plants. The value of not having restrictions means the community will have a more valued future income and satisfaction from water-related consumption activities (gardens), irrigated farms and businesses, including premium water-intensive industries.

Over the century the S.A. community, from mining to agriculture, and in the cities, has been substantially better off through access to Murray-Darling Basin piped supply, enabling reduced water supply volatility, not least in the Millennium Drought in 2006/7 (Caica 2010). While we refrain from hazardous estimates of these subjective total benefits, we do know that a *permanent second wave of water security* is now achievable, through tapping the oceans. These higher levels of water security have been demonstrated in Chile, Israel (now 80% self-sufficient in water) and elsewhere in the Middle East.

Our analysis is characteristic of the application of efficient systems dynamic applications combined with portfolio theory.[32] The desalination framework illustrates how economic development may no longer be blocked by water scarcity, climate change or drought, but may face costs of reverse osmosis including energy costs that should be less than for expanding dams.

While most of the time the future and moderate low average cost of water supply will reflect lower source costs in the Mount Lofty Ranges' catchments and the Mannum Adelaide pipeline for example, *security* in long-term water supply will come from the rainfall-independent supply sourced from oceans.

Other sources such as recycled wastewater, aquifer storage and treated stormwater may also become important, if more controversial in cost, reliability, volume and health terms (Appendix C below). Desalination via reverse osmosis filters out almost too many elements present in seawater (such as calcium which needs to be replaced), but health, safety and security are not a problem. Crucially, desalination modules face an effectively infinite ocean size[33]. Discharge of the brine back into the oceans is a technical issue that has been solved, not surprisingly given the source is the sea.

As in all infrastructure decisions, risk and cost parameters become decision variables and contract items for wholesale water supply corporations and firms free to contract either for expanded catchments, desalination water supply or imported water from the MDB. Other

[32] Tobin 1958.

[33] While issues such as discharge of brine into the gulfs initially caused concern, monitoring of discharge has revealed no significant issues. Research has documented the relatively low cost and consequence of returning higher saline water to the oceans, simply by dissipating at moderate distances out to sea and monitoring adjacent sea life. Refs from ACCIONA check with NCEDA.

substitute sources - aquifers, tanks, treated wastewater and stormwater will have commercial and environmental value, but not as base supply as population expands.

One major uncertainty clearly relates to the energy cost component of reverse osmosis. In Adelaide as for other desalination plants, governments have tended to make energy costs higher than necessary in the grid, because of environmental pressures to use renewable sources. This differential sourcing of energy explains much of the gap between public reporting of desalination costs say in Israel (Sorek), Singapore and Adelaide. The energy cost dimension for desalination is a matter we see as a key to future research, given the indicated scope for lowering costs and improving efficiency in treatment, water allocation and use. (In Kwh terms Adelaide, Israel (Sorek) and Singapore are very similar costs per kilolitre of desalinated water – a matter to be documented.)

Regardless of facts or politics, and plausible cost revisions, our cost analysis shows that economic and population growth means desalination should be an integral part of Adelaide's efficient bulk water portfolio as the century unfolds, as land for catchments and dams becomes relatively more expensive and risky, and as drought uncertainties make essential water trading vulnerable to drought, unlike desalination.

Appendix A.

Figure A1: Water Supply Sub-Model, Adelaide

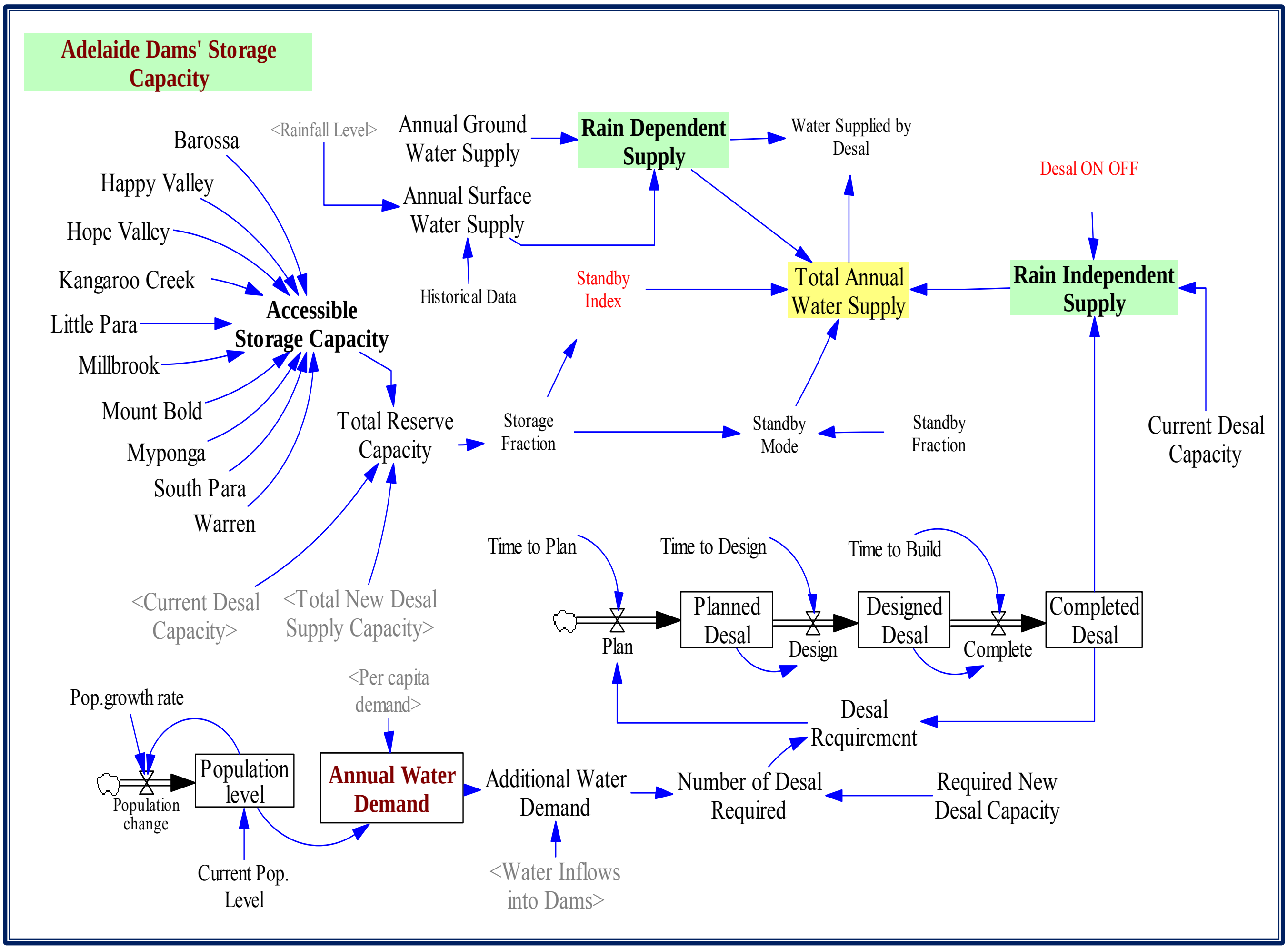
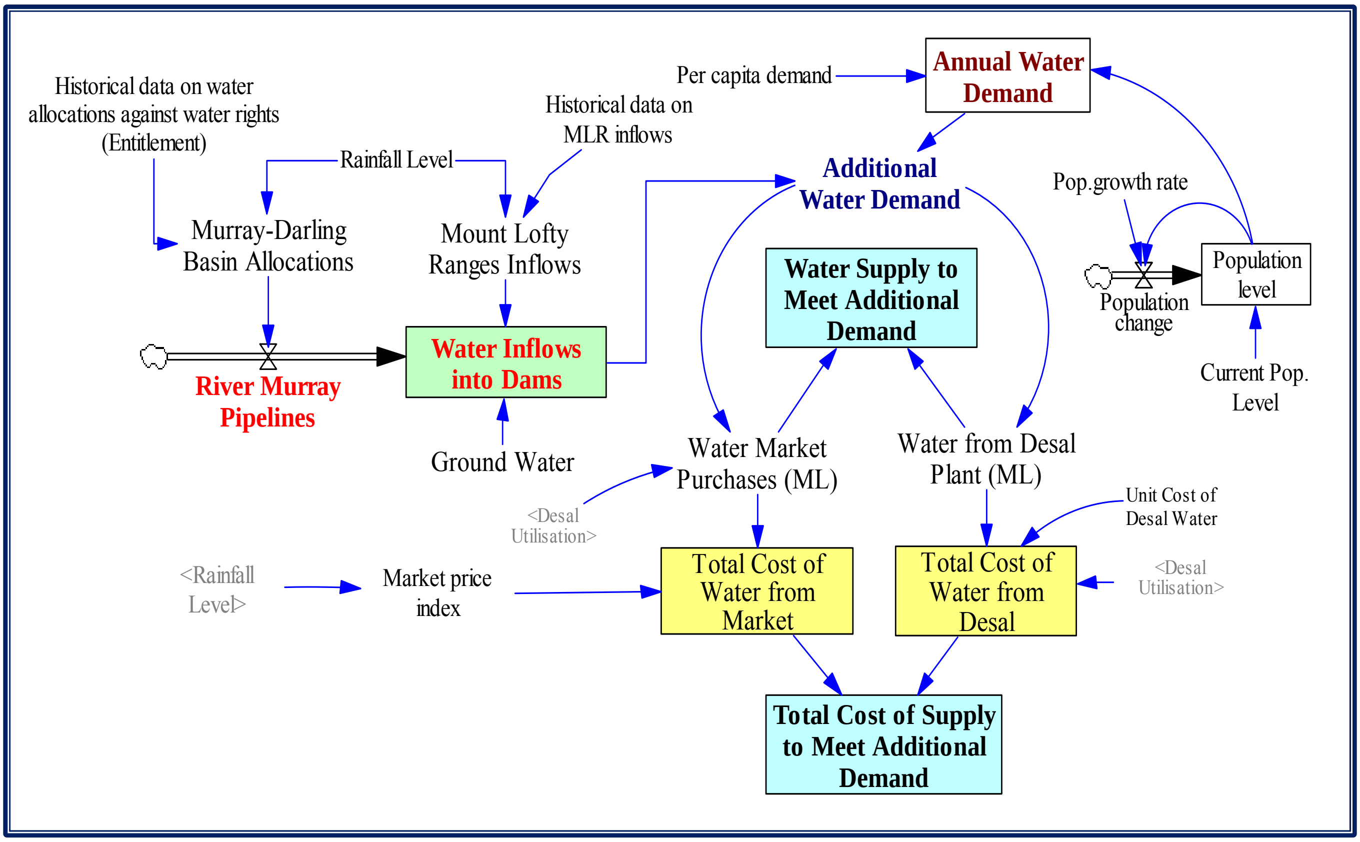


Figure A2: Water Market Sub-Model, Adelaide



Appendix B.

Baseline Assumptions

Our key assumptions are summarised in Table B1 below.

Table B1: Baseline assumptions for Adelaide's water supply and demand

Variable	Baseline Assumption	Source
Population - current	1.29 million	ABS, 2013
Population growth rate (%)	Default 1.2%	ABS, 2011
Current water use - Litres per person-day	340 LPD 228 residential/112 non-residential)	SA Water, Annual Report, 2010. Residential water use: Water for Good, 2010.
Dam capacity – current	200 GL/p.a.	SA Water, 2014
Desalination Capacity - current	100 GL/p.a.	SA Water, 2014
Desalination capital costs	$A1.2billion* per 50 GL/p.a.	Scarborough et al., 2014
Operating cost of desalination plant/s (100 GL/p.a.)	$A1.0/kL + $30 million (Depending on water order)	Technical Report Series 14/12. Goyder Institute for Water Research, 2014
Operating cost of new desalination plant including energy, pumping and membrane maintenance (50 GL/p.a.)	$A1.0/kL + $15 million	The mothballing cost assumed to be $15 million for desalination plant at 50 GL/p.a. capacity.
New dam capital cost	$A1.7 billion* per 100 GL	Scarborough et al., 2014
Dam operation costs	$A0.24/kL – Water from Mount Lofty Ranges $A0.44/kL – Water from River Murray $A0.36/kL – Ground water	Technical Report Series 14/12. Goyder Institute for Water Research, 2014
Capital cost of new pipeline	$A300 million per 100 GL/p.a.	Authors'
Maintenance cost of new dams and desalination plants	3.5% of capital cost	Authors'
Market price of water	Varying $A0.50-$A2.50/kL	Authors'
Model time bound	100 year	Authors'
Time interval of simulation	1 year	Authors'
Water storage to demand ratio	Varying 1 to 1.25	Authors'
Social discount rate %	1.5%	Scarborough *et al.*, 2015
Size of new desalination plant or module	Default 50 GL	Scarborough *et al.*, 2015
Size of new dam	100 GL	Scarborough *et al.*, 2015
Water entitlement	Default 650 GL/5 years	SA Water, 2014

*2013 Australian dollars

Appendix C.

Recycled wastewater – an efficient alternative to desalination?

This study focused on preferred long term water supply portfolios and cost options for a growing metropolitan Adelaide, including water from Murray Darling Basin, Mount Lofty Ranges, aquifers and the desalination plant. While recycled wastewater and storm water in principle could be part of the mix, the quantities and costs involved have been shown to make them peripheral rather than core components of base load water supply.

While waste and storm water can be treated to high potable water standards, as in Singapore with their "New Water"[34], the techniques *which include reverse osmosis* and other and treatment technologies are themselves thus more expensive in terms of capital and operating costs than using ocean water for desalination.

Tank water is also generally more expensive in capital cost terms per kilolitre (kL) and is also disadvantaged by being unavailable after short periods of drought[35].

There are three main wastewater treatment plants in Adelaide with combined recycling capacity of 58.55 GL/year[36] which could be upgraded up to 98.55 GL/year. The problem is that wastewater treatment plants are significantly more capital intensive, e.g. the Glenelg Recycled Water Project supplies only 3.8 GL/year of recycled, non-potable water to Adelaide Parklands at a capital cost $77.29 million (in 2013 dollars).[37] A 50 GL/year non-potable capacity plant would involve capital costs of approximately $1.8 billion[38], a similar capital cost to the Adelaide desalination plant with double the capacity but for 100 GL/year of *potable* water. Clearly on capital cost grounds large wastewater treatment plants do not currently stack up in

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[34] The four stage "New Water" procedure in Singapore starts with conventional pond and other primary removal of unwanted materials; the second stage uses microfiltration to remove suspended solids, colloidal particles, disease-causing bacteria, viruses and cysts leaving only dissolved salts and organic molecules. The third stage uses reverse osmosis (RO) to get rid of bacteria and viruses plus all manner of unwanted heavy metals, nitrates, chlorides, sulphates, and pesticides for example, thereby creating potable water. The fourth stage aims to make the water pass taste tests and standards and adds alkaline chemicals to restore pH balance.

[35] See "Australia's Urban Water Sector" report of the Productivity Commission, August 2011 P 98 which concludes "There is evidence to suggest that rainwater tanks are generally not cost effective for households, although performance varies from place to place (Marsden Jacob Associates 2007b)".

[36] The 58.55 GL/year includes Bolivar plant (38.325 GL/year), Christies Beach plant (16.425 GL/year) and Glenelg plant (3.8 GL/year).

[37] See Marchi, Dandy and Maier, 2014.

[38] Calculation was made based on proposed capital cost of $20,342/ML/year for the upgrade of plant capacity (see Marchi, Dandy and Maier, 2014, p.47) plus cost assumption of used capital at 5% per annum over 30 years.

competition with desalination plants[39]. Similarly, while the operating costs of wastewater recycling varies, best estimates are about \$2.00/kL, significantly more than desalinated water (about \$1.3/kL) and other sources. [40]

While the recycled water is, like desalinated water, climate independent, and allows S.A. to reduce the amount of wastewater entering Gulf St Vincent and reduces the use of potable water for non-drinking purposes its cost remain excessive, and far higher than MDB water most of the time.

[39] A separate example is the Western Corridor Water Recycling Scheme (Queensland) with a capacity to produce up to 232 megalitres of purified recycled water daily (about 85 GL/year). The capital cost was \$2.5 billion (Final Progress Report: Western Corridor Recycled Water. Queensland Government, 2009).

[40] For example, the operating cost of the Rouse Hill scheme in Sydney were anticipated to be in the order of 4/kL (\$5.19/kL in 2013 dollar). However, irrigator will not buy water at this price, and as an incentive, it was due to be sold at \$0.27 per kL (for cost figures see Marchi, Dandy and Maier, 2014). This difference in cost needs significant State subsidies every year.

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